Preprint
UCRL-JC-150982

Feasibility of thin Fresnel Lens use in Multi-kJ, Short Pulse Laser Systems

I. Jovanovic, S. N. Dixit, B. Wattellier, M. R. Hermann, C. P. J. Barty

This article was submitted to
2003 Conference on Lasers and Electro-Optics Quantum Electronics and Laser Science Conference, Baltimore, MD, June 1-6, 2003

U.S. Department of Energy

Lawrence
Livermore
National
Laboratory

November 18, 2002

This work was performed under the auspices of the United States Department of Energy by the University of California, Lawrence Livermore National Laboratory under contract No. W-7405-Eng-48.

Feasibility of thin Fresnel lens use in multi-kJ, short pulse laser systems

Igor Jovanovic, Sham N. Dixit, Benoit Wattellier, Mark R. Hermann, and C. P. J. Barty
Lawrence Livermore National Laboratory, Mail Code L-490, 7000 East Avenue, Livermore, California 94550
jovanovic1@llnl.gov

Abstract: Recently-developed, thin-Fresnel-lens technology offers the potential for transmissive focusing of high-peak-power, ultrashort-duration laser pulses. Calculations of the transverse and longitudinal spectral blurring effects of thin Fresnel lenses when used to focus ultrashort, high-energy laser pulses are presented.

OCIS codes: (050.1970) Diffraction and gratings: Diffractive optics; (140.7090) Ultrafast lasers

High-peak-power, short-pulse laser systems have traditionally used reflective optics to focus laser pulses to avoid linear and nonlinear phase accumulation inherent to refractive optics. Typical recompressed pulses from a large Nd:glass laser have an unfocussed intensity of order 1 TW/cm^2. When incident on a transmissive fused silica optic, such pulses would produce a B-integral of ~20 cm^{-1}-200 cm^{-1}. High B-integral (>1) will lead to focal spot distortion, and possibly to self focusing and damage of the focusing optic. Reflective parabolic focusing optics eliminate the B-integral problem and are widely used in short pulse laser systems. However, the surface quality requirements for a reflective optic are typically much higher, and their tolerance to beam pointing and divergence is up to one order of magnitude lower than for a corresponding transmissive optic.

Recently, Lawrence Livermore National Laboratory has developed the capability to produce, high quality thin Fresnel lenses. [1] Lenses with thicknesses <200 μm and apertures up to 60 cm have been shown to be capable of producing diffraction-limited beam quality focal spots. Transmission through such lenses would produce negligible B-integral (<<1). However, chromatic aberrations inherent to Fresnel lenses will distort the focal spot size and pulse duration. Such distortions will be strong functions of the input pulse bandwidth and the f-number of the optical system. Next generation large laser systems such as the National Ignition Facility (NIF) in the US and the Laser MegaJoule (LMJ) in France have the potential to produce multi-kJ short pulses and operate with high f-number final optics. In this paper we numerically evaluate the feasibility of thin Fresnel lens use for focusing of high-power laser pulses.

The chromacity of the Fresnel lens results in reduced transverse focusability of a spectrally broadband beam. In Figs. 1 and 2 we show representative results of our calculations for transverse focal spot blurring assuming an input beam profile similar to that which will be produced by NIF or LMJ and a bandwidth corresponding to a 2-ps transform-limited pulse.

A beam incident on a Fresnel lens also experiences radially variable transit time to focus. We calculated the pulse duration at focus for an incident Gaussian temporal pulse (Fig. 3).

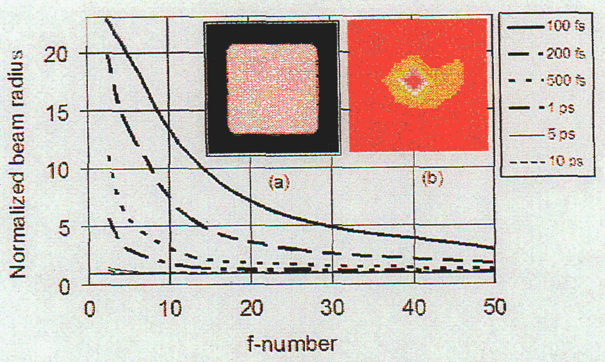

Fig. 1. Transverse focal spot blurring as a function of the Fresnel lens f-number, for several representative pulse widths. Calculated broadband beam radius is normalized to the monochromatic focused beam radius. Inset: (a) NIF near-field amplitude profile, (b) NIF focal spot, for f/#=10 and 100-fs pulse duration.

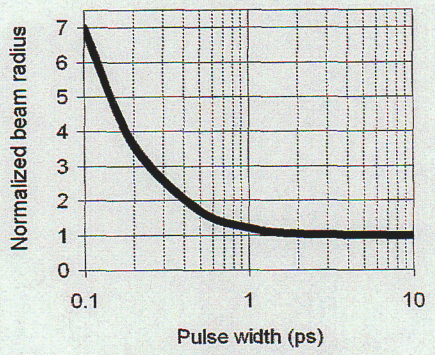

Fig. 2. Transverse focal spot blurring as a function of transform-limited pulse width, for f/#=17. Calculated broadband beam radius is normalized to the monochromatic focused beam radius.

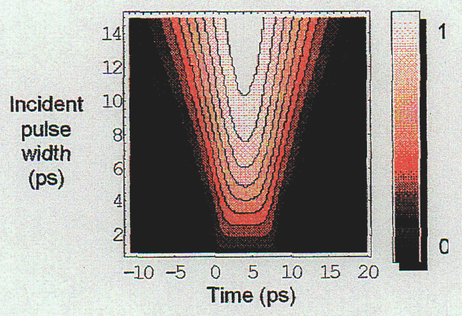

Fig. 3. Focused pulse intensity, for a range of incident pulse durations. Pulse intensity is normalized to the intensity of an ideally focused monochromatic beam.

If the criteria for acceptable pulse focusing is defined as <50% spatial blurring, the minimum acceptable f-number for focusing of 1-ps pulses is ~12.5. For a <50% decrease in peak intensity of an incident 0.4-m diameter, 1053-nm pulse, focused with f_0=8 m, the minimum pulse width allowed on the lens is ~4 ps. While those requirements may be too restrictive for some short-pulse laser systems, they are acceptable for applications such as hard x-ray generation with laser based relativistic electrons [2] and could be applicable to low energy applications such as precision micromachining, with high-average power CPA systems. Practical limits as a function of pulse bandwidth and lens f-number for a variety of short pulse systems will be presented.

This work was performed under the auspices of the U. S. Department of Energy by Lawrence Livermore National Laboratory under Contract No. W-7405-Eng-48.

References

1. I. M. Barton, J. A. Britten, S. N. Dixit, L. J. Summers, I. M. Thomas, M. C. Rushford, K. Lu, R. A. Hyde, and M. D. Perry, "Fabrication of Large-Aperture Lightweight Diffractive Lenses For Use in Space," Appl. Opt. **40**, 447-451 (2001).
2. T. Guo, Ch. Spielmann, B. C. Walker, and C. P. J. Barty, "Generation of hard X-rays by ultrafast terawatt lasers." Rev. Sci. Instrum. **72**, 41-47 (2001).